

A horizontal bar with a gradient from purple to red, pointing to the right.

Shape Memory Composite Applications for Deployable Membrane Reflectors

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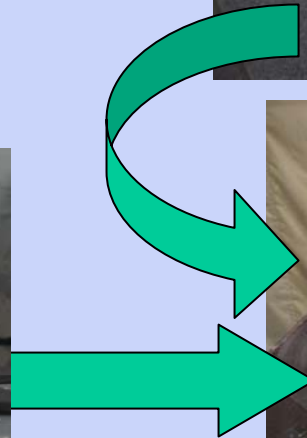
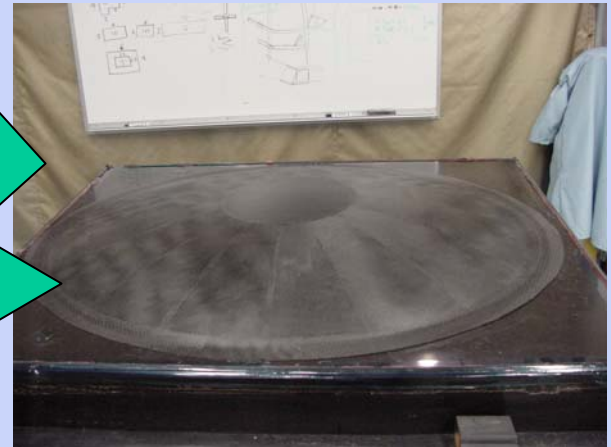
Mirror Technology Days 2006

Laminated Deployable Optics

The Best of Two Technologies

Nickel electroformed replica:
Smooth, accurate optical
surfaces

Shape memory polymer- carbon
fiber reinforced, for light weight
and controllable deployment



Deployable, lightweight reflectors

NASA Needs for Deployable Reflectors

- **ESTO Workshop (2003) identified multiple mission needs for deployable imaging systems requiring apertures of 1 to 5 meters and larger**
 - Microwave- soil moisture, temp radiometry, cloud heights
 - IR- temperature measurement, radiometry
 - SAR
 - Visible- Lasercom, LIDAR
- **Deployable reflectors are an enabling technology for many missions**
 - Lighter weight and stiffer optics
 - Instrument capabilities enhanced at larger apertures
 - Cross enterprise value to OSS, Exploration missions

Primary Objective of Shape Memory Optics Technology Demonstration

Goal: Make deployable, stiff, lightweight reflectors for earth science space applications

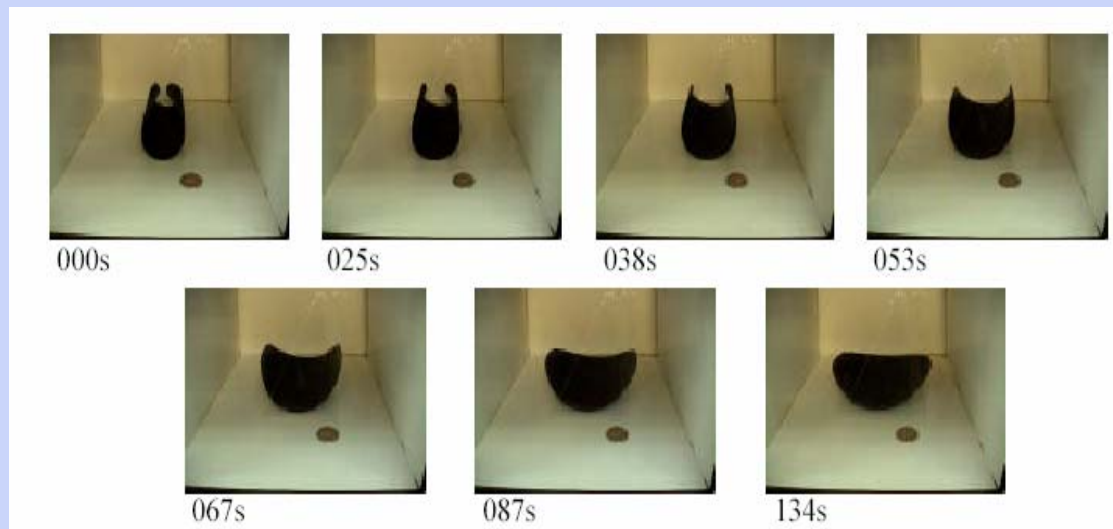
Result: Shape Memory Composite material allows deployable microwave reflectors with performance comparable to rigid reflectors, but optical applications initially considered will require more development. Nickel surface development is mature enough for VU-VIS-IR applications

Applications:

- Use shape memory composites to provide deployable RF band reflectors with better surface accuracy and finish than the current metal mesh reflectors**
- Light bucket type optical systems where light collection aperture is more important than surface accuracy**
- GEO LIDAR and LaserCom applications**

Why Consider Shape Memory Composite Reflectors?

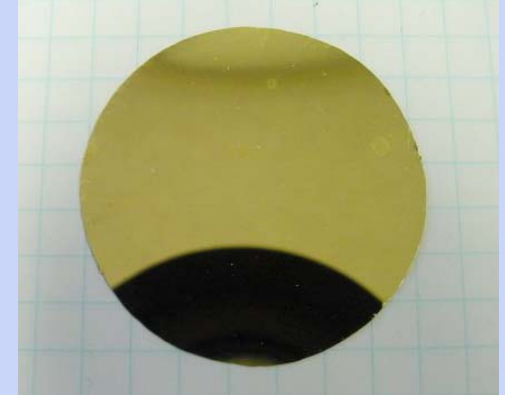
- Replication – Reduced production time and cost
- Larger design parameter space; low mass, compact packing, high stiffness, segmented or monolithic
- Adaptable to simple in-space deployment and active control
- Better surface accuracy than mesh and inflatable



Laminated Reflector Concept Replicated Nickel/Composite

- **Surface Replication: low stress nickel**

- Replicates optical figure
- Good surface finish (<2nm RMS)
- Tough, flexible, established processes
- Etched for reliable adhesion



- **Shape memory resin composite**

- High stiffness, low mass (1-5 kg/m²)
- Replicated Production
- Low outgassing (< 0.16% TML)
- Deployable
- Composite adjusted to match nickel CTE



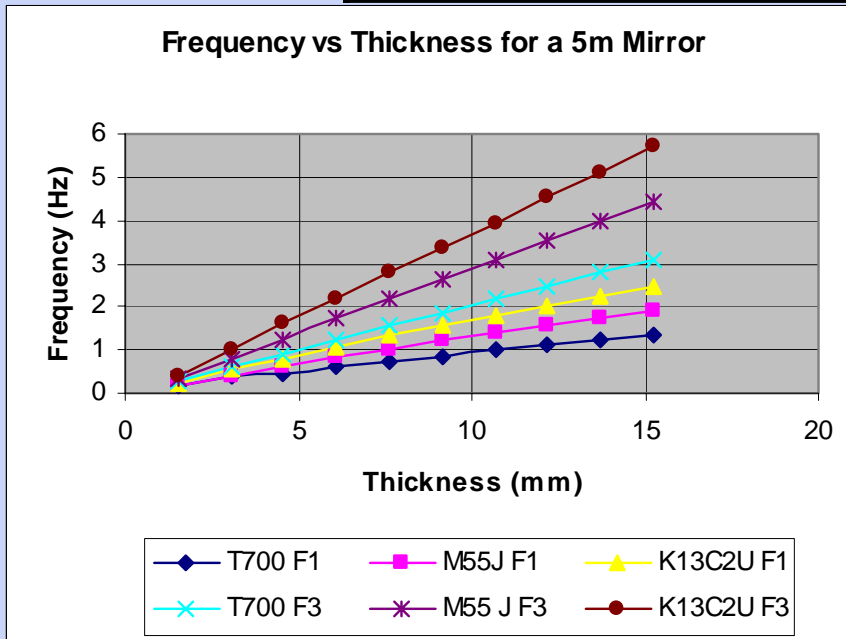
Detailed Modeling Goals

- **Update material constructions**
 - Symmetric laminations for stability and uniformity
- **Comparison with strain measurements made on samples**
 - New constructions fabricated and tested
- **Scalability**
 - Utilize scaling methods developed for other large space structures
- **Thermal deformations**
 - Balanced constructions minimize thermal deformation level
- **Resonant Frequency**
 - Mass / size are drivers for fibers, thickness, # layers, deployability
- **Thermal actuation**
 - Analysis demonstrated feasibility of deployment via solar heating, with appropriate thermal coatings

Resonant Frequency for a 5m Mirror

Using the same
(0.060 in) thickness:

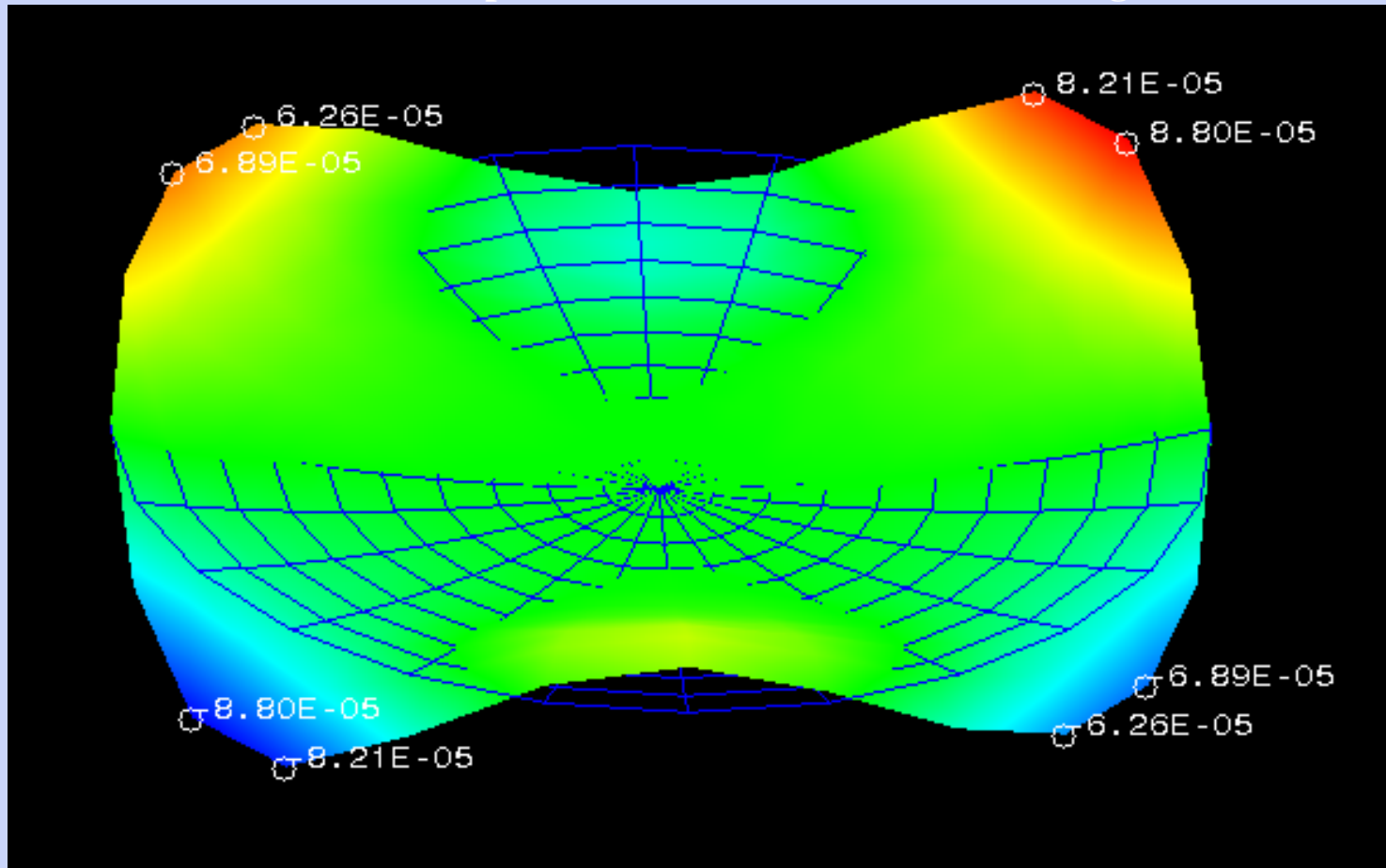
Material	F1 (Hz)	F2 (Hz)	F3 (Hz)	F4 (Hz)
T700	0.145	0.290	0.268	0.399
M55J	0.191	0.298	0.338	0.565
K13C2U	0.239	0.386	0.415	0.736



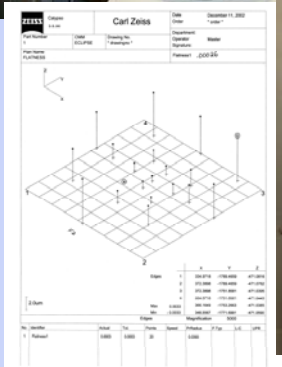
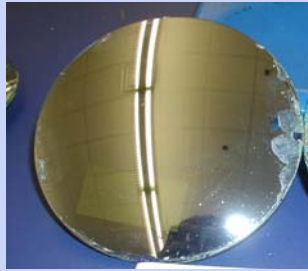
5m Mirror Mass:
(from NASTRAN FEM)
1.5 mm thick: 58 kg
7.6 mm thick: 274 kg
15 mm thick: 544 kg

Shape Change for a $\pm 1^\circ$ Side to Side Gradient are minor effect

Deformed Shape for a T700 Mirror with Ni Coating

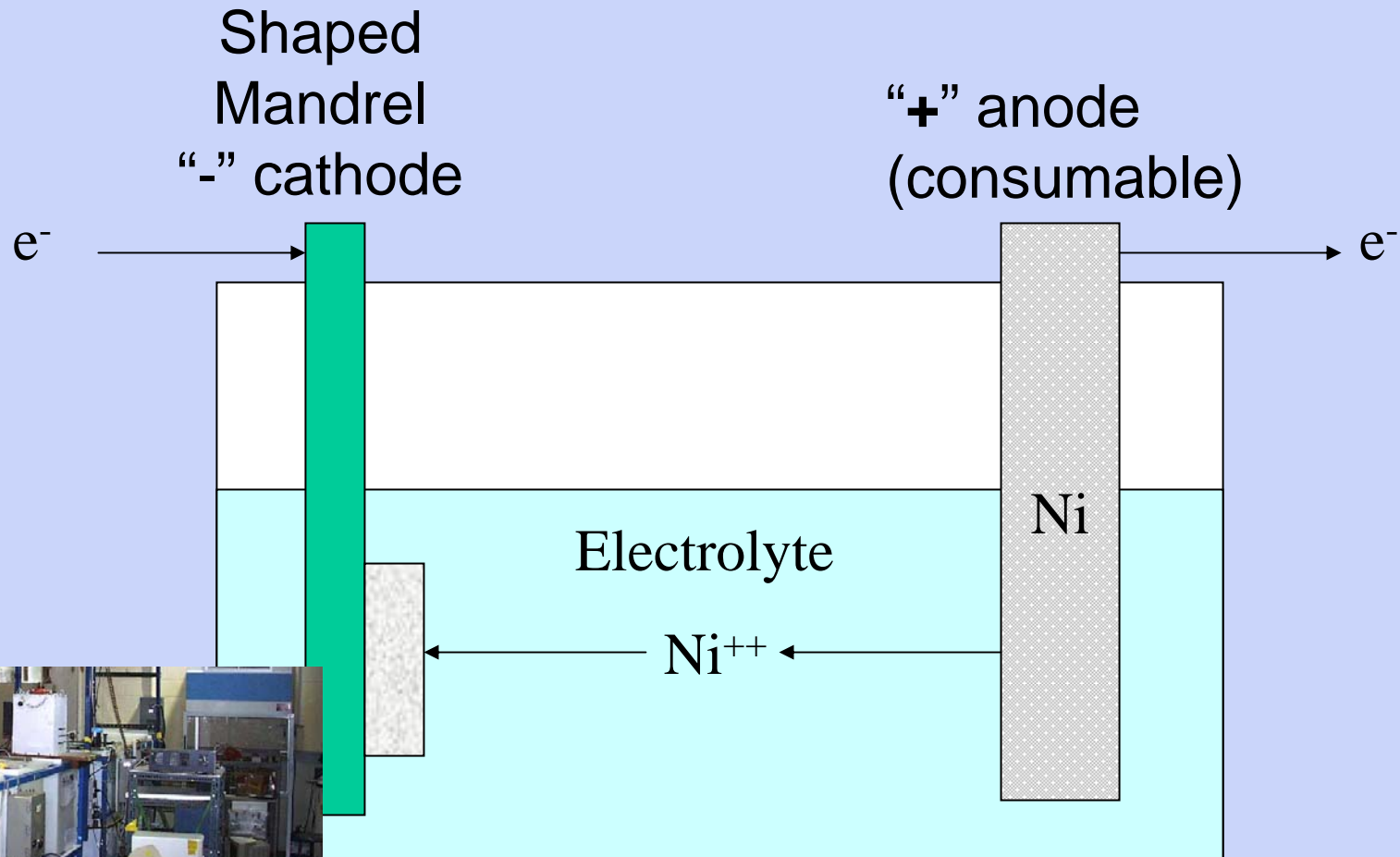


Replication process



- Polish and prepare mandrel
- Electroplate Nickel
- Etch Nickel for adhesion
- Lay-up and cure composite
- Remove from Mandrel
- Characterize surface
- Prepare for stow and deploy testing and further measurement

Low Stress Electroplating Forms the Reflective Surface

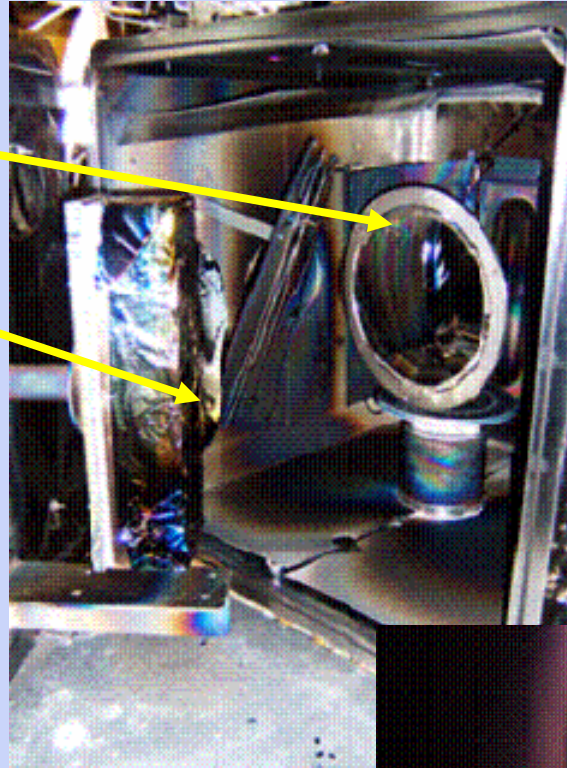


Process adapted from fabrication of Wolter X-Ray optics

Plasma Etching Prepares Nickel Electroforms for Composite

Fixture and mirror mandrel

The cathode structure and sputtering target

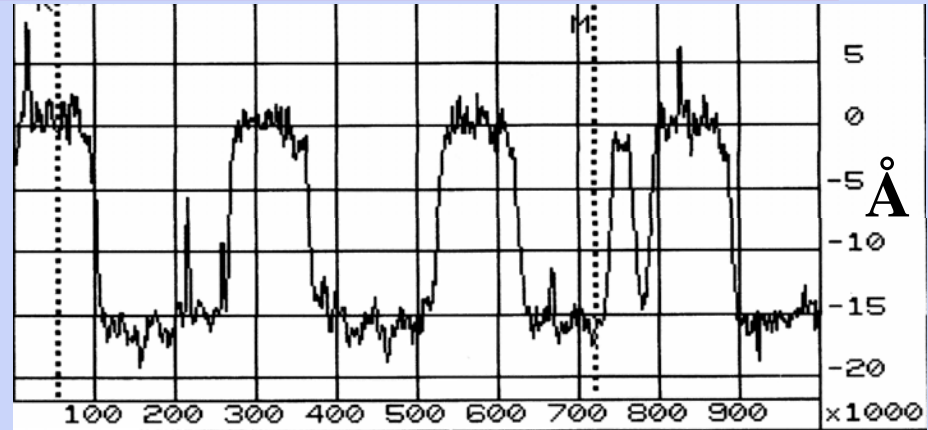
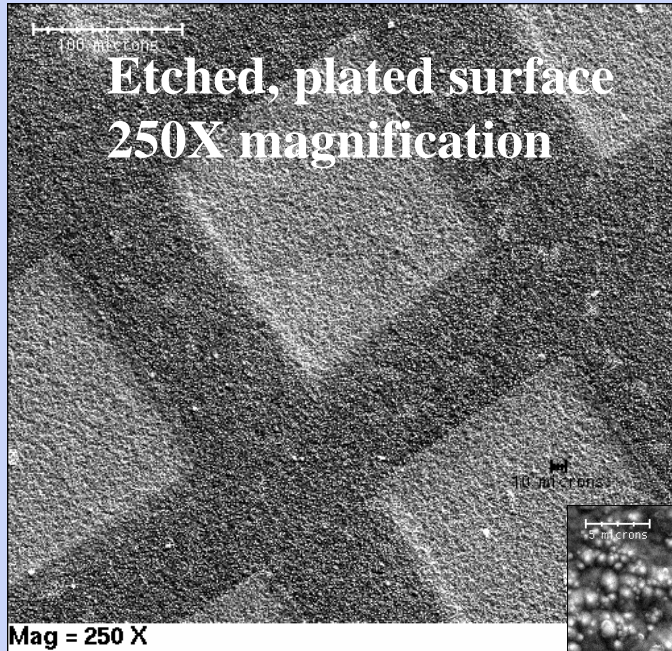


Rear surface of 30cm plasma-etched electroform

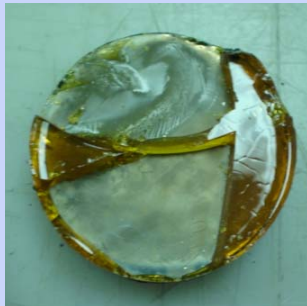
The plasma etching viewed through a quartz window
Color is characteristic of the argon plasma



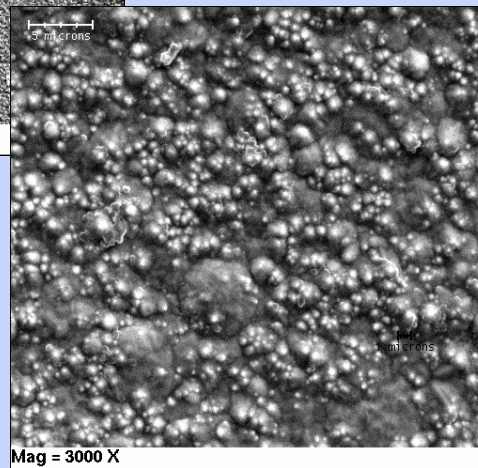
Etching of Nickel Increases Roughness Profile and Improves Adhesion



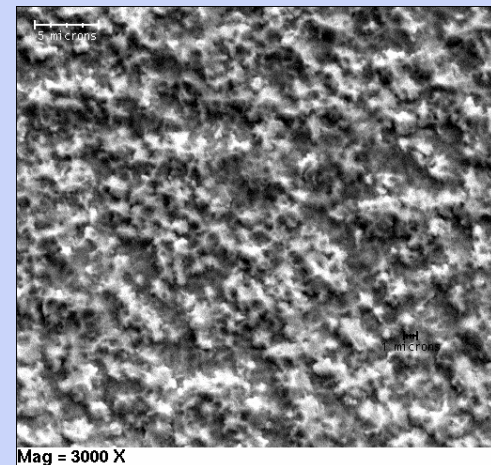
Mesh Profile (microns)



Resin fails before
nickel adhesion



As-plated



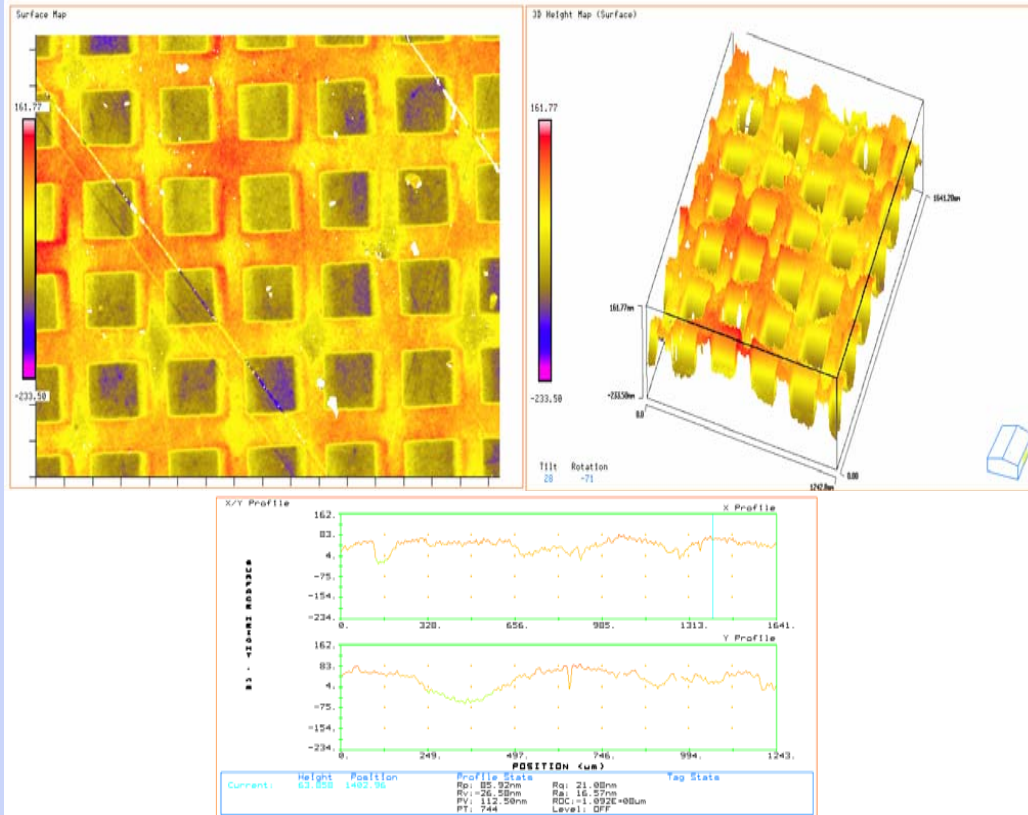
3000 X

Etched

Etched profile of nickel surface

White light
interferometric
image of etched
surface profile

Waffle pattern
interlocks with
composite resin for
durable adhesion



Title :		Statistics of Surface: 95-26
Part ID :		Rp: 161.77nm Rq: 61.39nm Area: 1641.28x1242.80um
Map Name :	ADE/PHASE SHIFT	Rv: -233.50nm Ra: 54.11nm Mag : 5.0
Operator :	MapVue - Surface Mapping Software	PV: 395.28nm Rsk: -0.36 DATE: 02-25-2005
Temp :	Version 6.35 (c) 1985-2001	PT: 355077 Rku: 1.84 TIME: 14:35:54
Time :		
Comment :		

Shape Memory Polymers Application

Cured shape---

Stow/Deploy
actuation--

Stowed ---

- **Replication**

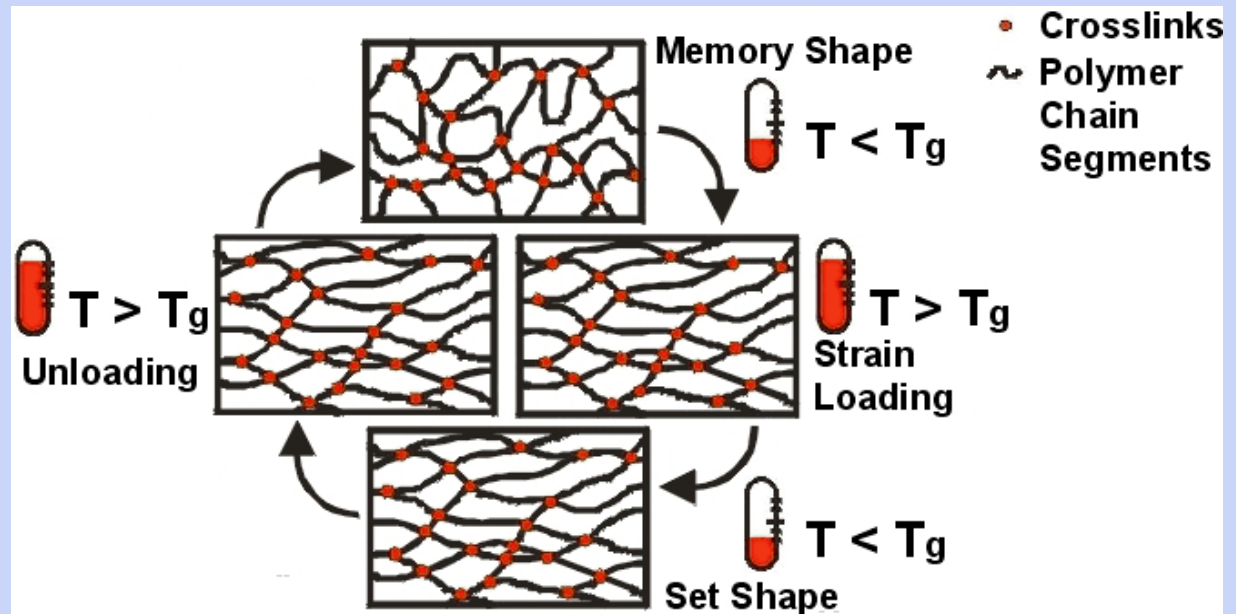
- Replicate surface from master in manufacturing processes

- **Actuation**

- Store and release mechanical energy

- **Reconfiguration**

- Temporary modulus reduction to enable shape change



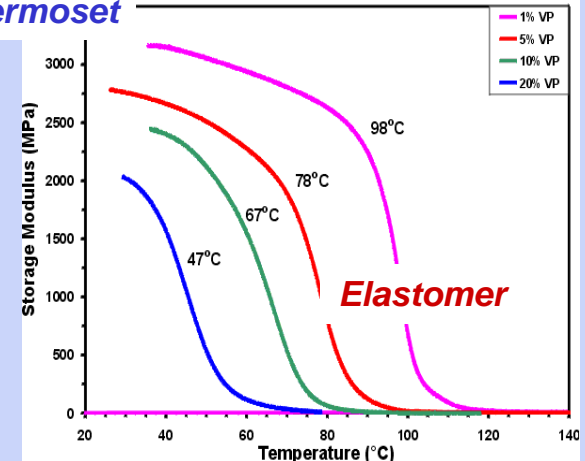
SMP Development - Cyanate Ester

- **CE polymers are already used in space**
- **Conventional CE transformed to SMP**
 - Fully cured, cross-linked for stability
 - Required new polymer design
- **CE shape memory polymer results:**
 - Deformation-recovery cycle demonstrated
 - Activation temperature of 160°C
- **Improvements Continuing**
 - Enhanced strain recovery
 - Increased toughness

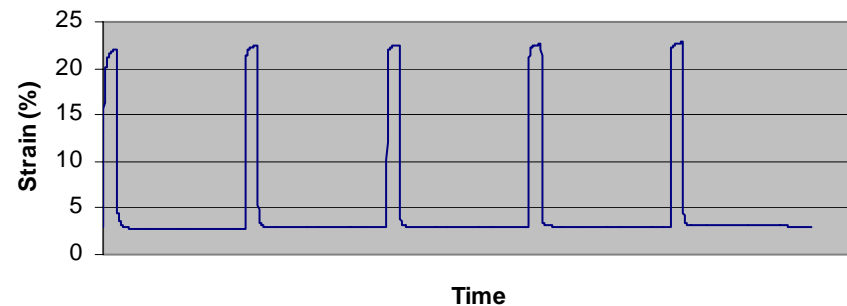
Cyanate Ester SMP

More uniform recovery from 23% strain achieved. $T_g = 174^\circ\text{C}$

Thermoset



6535 Formulation

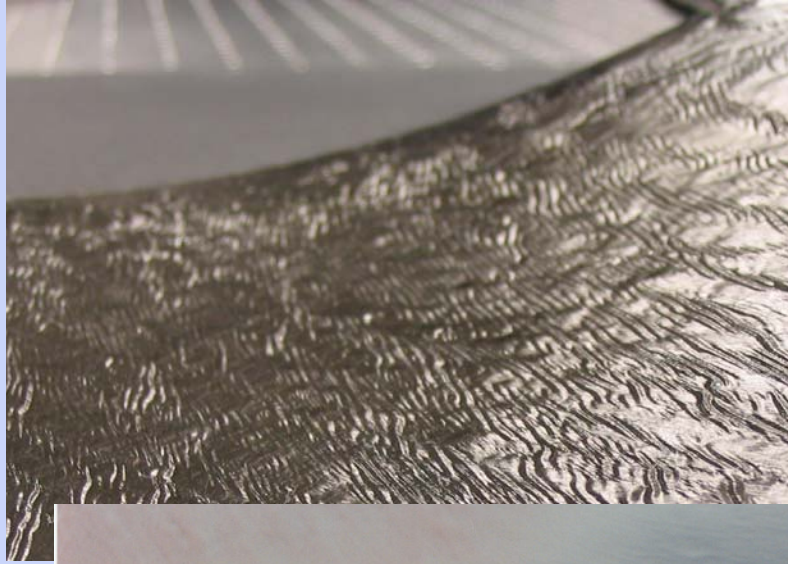


Cyanate Ester Shape Memory Resins- Acceptable Outgassing

- Total Mass Loss (TML) and Condensed Outgassing Product (COP) tests on cyanate ester SMP and composites found them to be space-qualifiable

Log #	Material	TML %	COP %
58	SynLam TM with 3D Carbon Fabric	0.292	0.027
59	Triaxial weave Carbon Composite	0.059	0.012
66	Neat CE SMP Resin	0.147	0.006
-	Acceptable levels	1.0	0.1

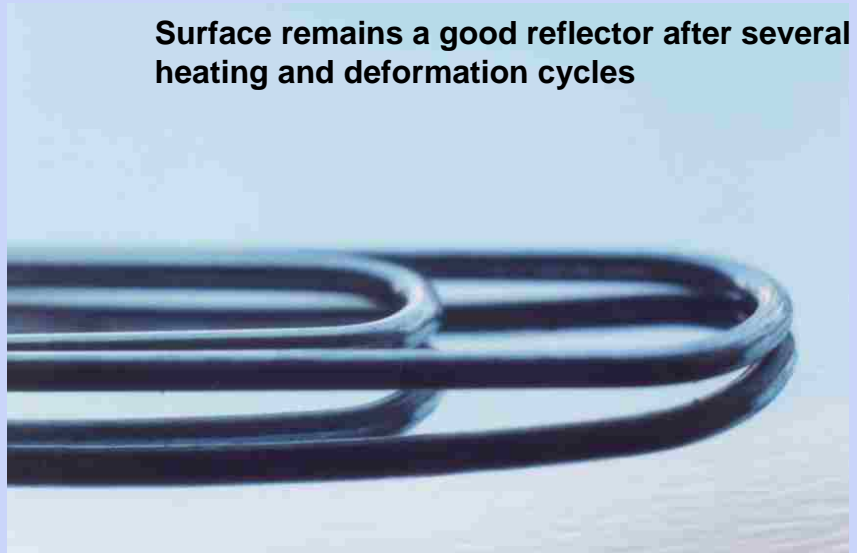
Deployed Mirror surface undamaged by deployment



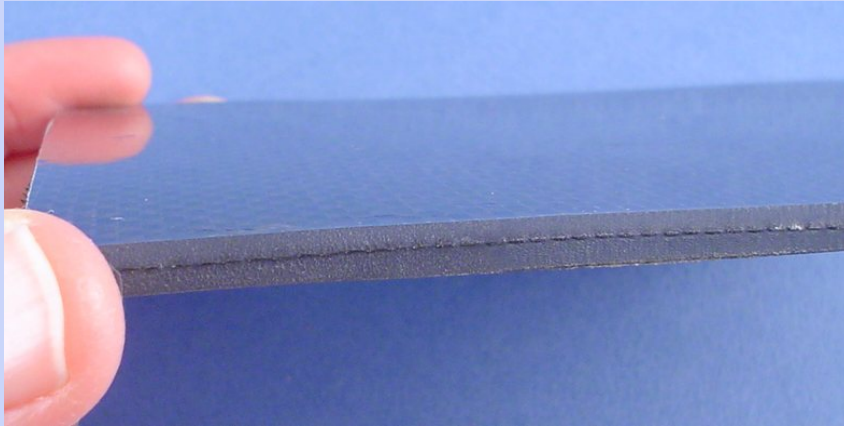
Surface damaged by deployment
only where delaminated

- Buckling was observed only where delaminated
- Remains smooth after several heat cycles
- Underlying fibers and resin undamaged

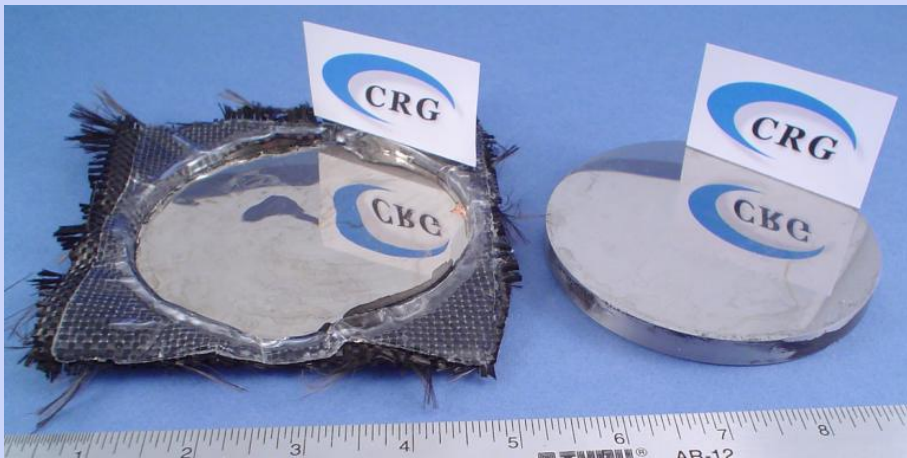
Surface remains a good reflector after several heating and deformation cycles



Print through remains a challenge, but is significantly reduced



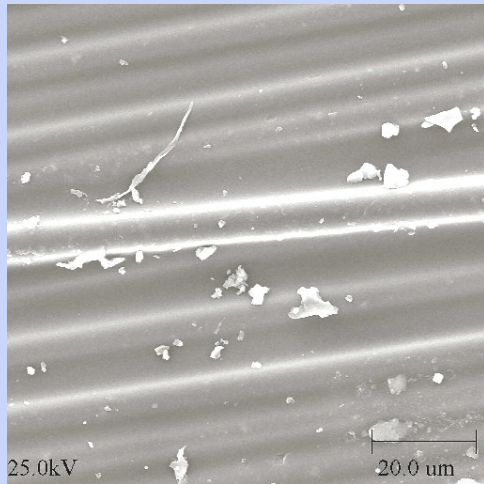
- Fiber-resin CTE mismatch produces print through
- Sandwich approach is improvement, without fibers near surface
- Neat (resin rich) layer surrounds fiber reinforcement
- Nanofibers and alternate filler reinforcement being investigated



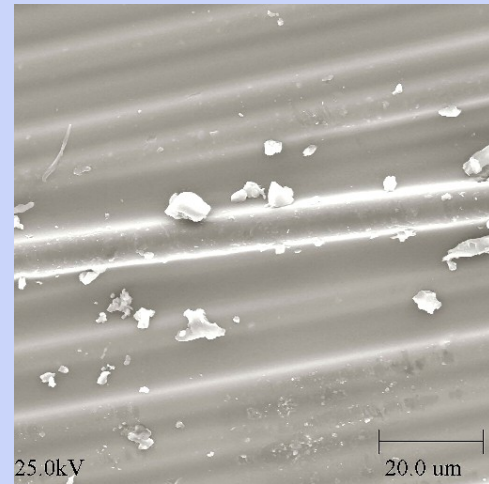
- Neat resin layer reduces fiber print-through effect, but nickel-thermal mismatch caused waviness

Composite Thermal & Bending Fatigue Test

- **Thermal Cycling showed no damage or changes**
Samples of composite have been temperature cycled 10x between –20C to +50C.



1000x SEM before cycling

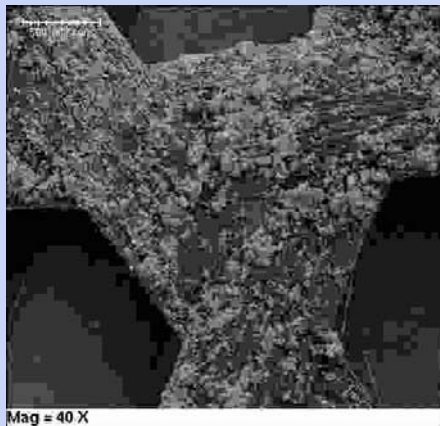


1000x SEM after cycling

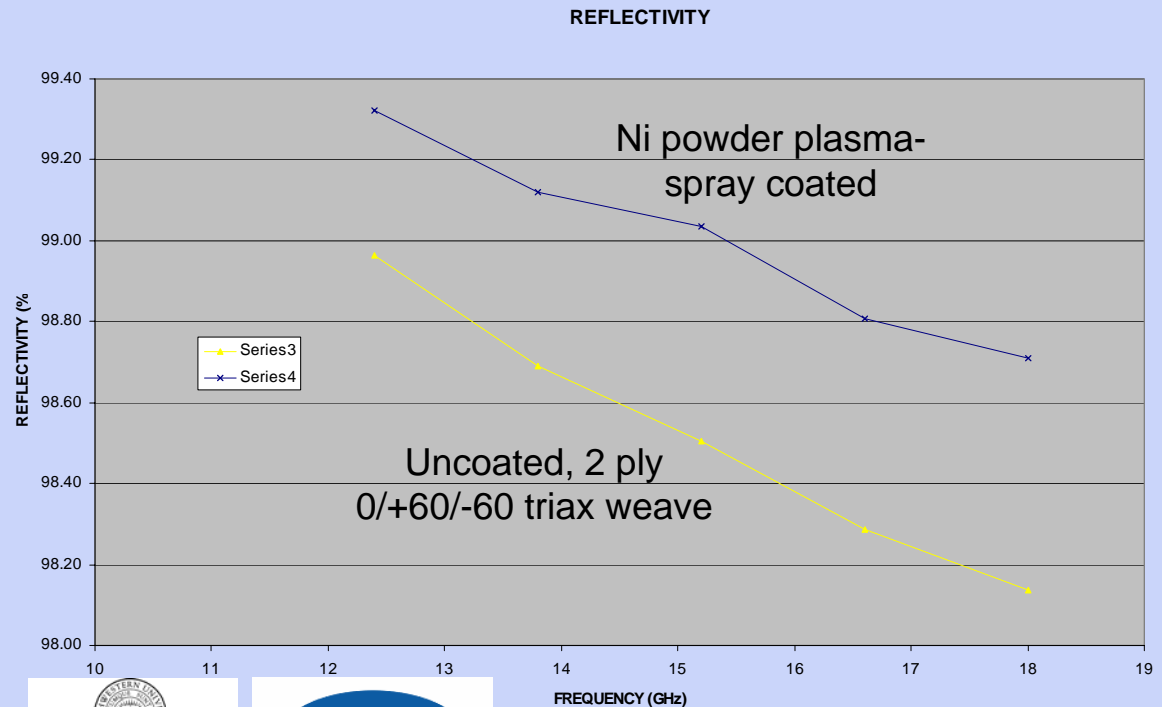
SEM photos before and after from 25x to 3000x show no change or microcracking in the resin or fibers. Microscope inspection of composite samples subjected to repeated cycling from room temperature to +200C have not shown evidence of resin or fiber cracking.

High Microwave Reflectivity

- Several sample constructions tested between 12-26.5 GHz
- Reflectivities uncoated are 94.5-97.5%
- Durable Plasma spray or plated coatings improve reflectivity to 99.5-97.5%, and adhere through multiple deployments

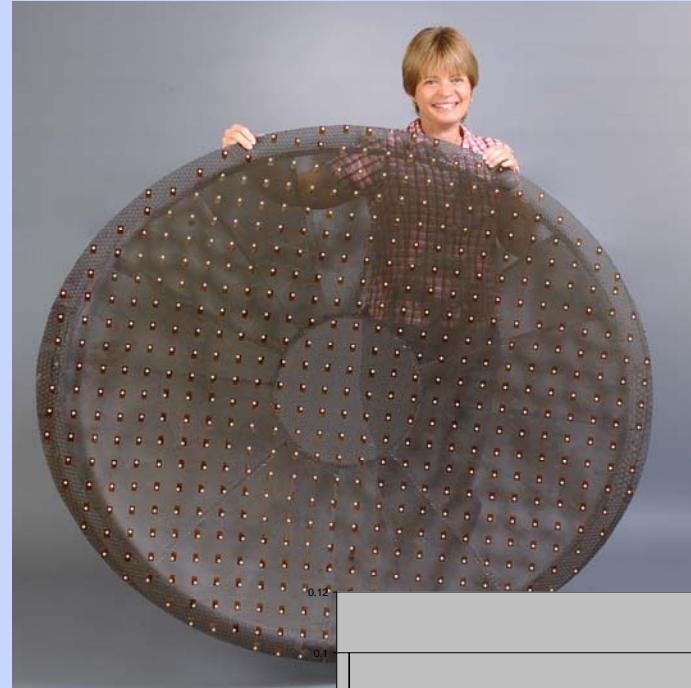


Ni powder
plasma-spray coated



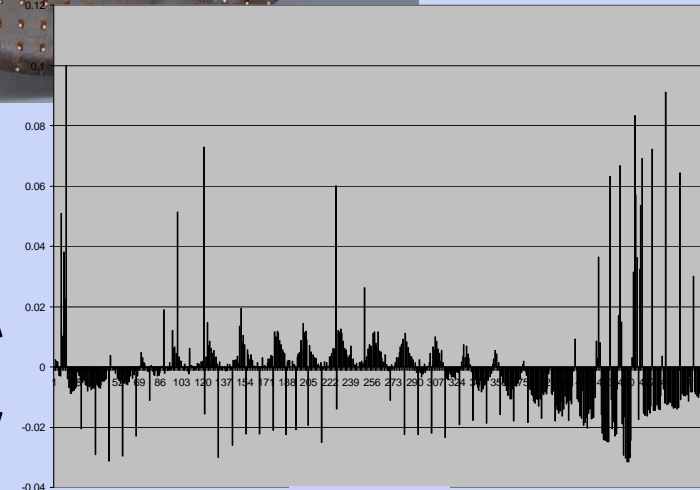
1m deployable reflector surface

Areal Density 0.4 kg/m²
Carbon fiber Triax Weave
Surfaces < 1mm RMS



**Stow-deploy
repeatability
+/- 0.5 mm**

1 mm



1 meter

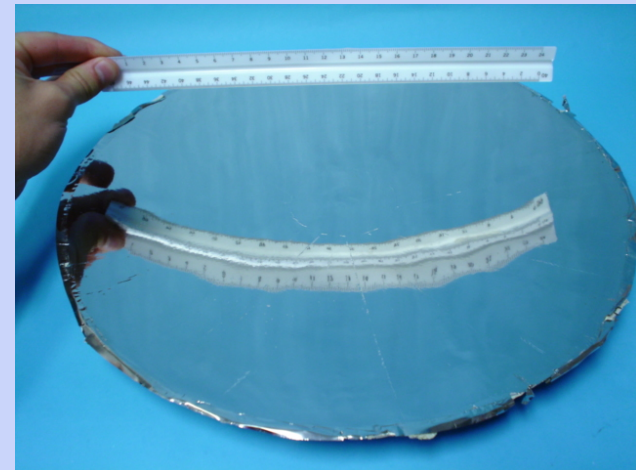
Current deployable reflector status

We have manufactured several test items of increasing size (up to 1.0 meter)

- Materials are low outgassing and space-stable
- Adhesion of metallization coatings demonstrated
- Figure accuracy as good as current rigid membrane reflectors, better than mesh

We are looking at other applications

- Deployable structures, beams
- Active shaping controls, metrology, dynamics & damping
- Heater/deployment implementation



Conclusions

- **Laminated nickel – composite optics can provide deployable, highly reflective surfaces without delamination or deterioration of metal surface and substrate**
- **Typical deployment accuracy is consistent with needs for 15GHz microwave reflectors of 1-2 meter diameter, and further development for surface accuracy adequate at higher frequencies**
- **Additional work needs to be done in:**
 - Resin chemistry (greater elongation, low CTE, low temp cure)
 - Structures (optimizing deployment, modeling in stow condition)
 - Durability verification in the space environment



Acknowledgements

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